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Comparison of age of peak swimming speed in elite backstroke swimmers at national and international level

Kollarz, C ; Knechtle, B ; Rüst, C A ; Rosemann, T

Abstract: Background:Previous studies suggested that the age of peak performance in freestyle swimming was 17 years for women and 19 years for men. Data on the age of peak swimming performance in other swim strokes such as backstroke are lacking. The present study investigated the changes in (i) swimming speed and (ii) age of peak swimming speed across years for elite female and male backstroke swimmers competing at both national and international level. Methods:The changes in age and swimming speed in 50m, 100m and 200m were analyzed for elite backstroke and freestyle swimmers at national level (i.e. Switzerland) and international level (i.e.finalists of World Championships) on 50m long coursefrom 1994 to 2011. Results: For all distances and disciplines, women reached the age of peak swimming speed at a younger age (18-23 years) than men (21-26 years). The age of peak swimming speed in backstroke and freestyle swimmers at national level was 1-2 years younger than in swimmers at international level. The age of peak swimming speed increased significantly ($p<0.01$) between 1994 and 2011 in 50m backstroke for women from 16 to 22 years and in 50m freestyle for men from 22 to 23 years in swimmers at national level. No changes in the age of peak swimming speed were observed in swimmers at international level for both swim styles across time for both sexes ($p>0.05$). Swimming speed increased across years in all distances and disciplines except for 50m backstroke in women at international level ($p>0.05$). Conclusion: Women reached in all disciplines the age of peak swimming speed at a younger age than men. Swimmers at national level were younger than swimmers at international level. Swimming speed increased in all distances and disciplines across years in swimmers competing at both national and international level.

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Research study

Comparison of age of peak swimming speed in elite backstroke swimmers at national and international level

C Kollarz[1], B Knechtle[1,2]*, CA Rüst[1], T Rosemann[1], R Lepers[3]

Abstract

Introduction

Previous studies suggested that the age of peak performance in freestyle swimming was ~17 years for women and ~19 years for men. Data on the age of peak swimming performance in other swim strokes such as backstroke are lacking. The present study investigated the changes in swimming speed and age of peak swimming speed across years for elite female and male backstroke swimmers competing at both national and international levels.

Materials and methods

The changes in age and swimming speed in 50 m, 100 m and 200 m were analysed for elite backstroke and freestyle swimmers at national level (i.e. Switzerland) and international level (i.e. finalists of World Championships) on the 50-m long course from 1994 to 2011.

Results

For all distances and disciplines, women reached the age of peak swimming speed at a younger age (~18–23 years) than men (~21–26 years). The age of peak swimming speed in backstroke and freestyle swimmers at national level was ~1–2 years younger than in swimmers at international level. The age of peak swimming speed increased significantly ($P < 0.01$) between 1994 and 2011 in 50-m backstroke for women from 16 to 22 years and in 50-m freestyle for men from 22 to 23 years in swimmers at national level. No changes in the age of peak swimming speed were observed in swimmers at international level for both swim styles across time for both sexes ($P > 0.05$). Swimming speed increased across years in all distances and disciplines except for 50-m backstroke in women at international level ($P > 0.05$).

Conclusion

Women reached in all disciplines the age of peak swimming speed at a younger age than men. Swimmers at national level were younger than swimmers at international level. Swimming speed increased in all distances and disciplines across years in swimmers competing at both national and international levels.

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Introduction

Several studies analysed the change of endurance performance with increasing age[1–3]. For endurance sports such as running, swimming, triathlon or rowing, peak performance was described at the age of ~35 years with a linear decline in performance until the age of ~70 years[2,4,5]. After the age of ~70 years, the performance declined exponentially[1–3,5].

For swimmers, the age-related performance decline in freestyle swimming showed differences regarding the distance and the sex, with a greater decline in long-distance performances such as 1,500-m freestyle and for women compared to men[2,3]. Schulz and Curnow[6] reported that women generally achieved peak swimming performance at a younger age compared to men. Literature, however, is discordant regarding the age of peak freestyle swimming performance in relation to different race distances. For freestyle swimmers, the age of peak swimming performance was described at ~21 years[7]. Fairbrother[8] reported that male freestyle swimmers achieved the age of peak performance for 50 m in their late 20s and early 30s. For 1,500-m freestyle, the age of peak swimming performance was achieved at ~18 years in contrast to the 50-m distance where the age of peak swimming speed was documented at ~23 years[7]. Schulz and Curnow[6] described a different development with a decline in the age of peak swimming performance with increasing race distance. Tanaka and Seals[3] claimed that men reached their fastest times for 1,500-m freestyle swimming between 25 and 40 years of age, whereas women achieved the fastest 1,500-m freestyle swimming times at the age of ~30–35 years. In contrast, peak performance in 50-m freestyle swimming was attained at the age of 20–30 years in both men and women[3].

In contrast to these disparate findings in swimming, data analyses of running showed an increase in the age of peak performance with increasing race distance[6,9,10]. The age of peak running performance has been investigated in 100-m and 200-m short-distance running[6], 800-m and 1,500-m middle-distance running[6], half-marathon running[9], marathon running[6,9] and ultra-marathon running[10].

Analysing the development of swimming performances of women compared to men, women`s performances constantly improved[6,11]. During the last century, a decline in the sex difference in performance for all

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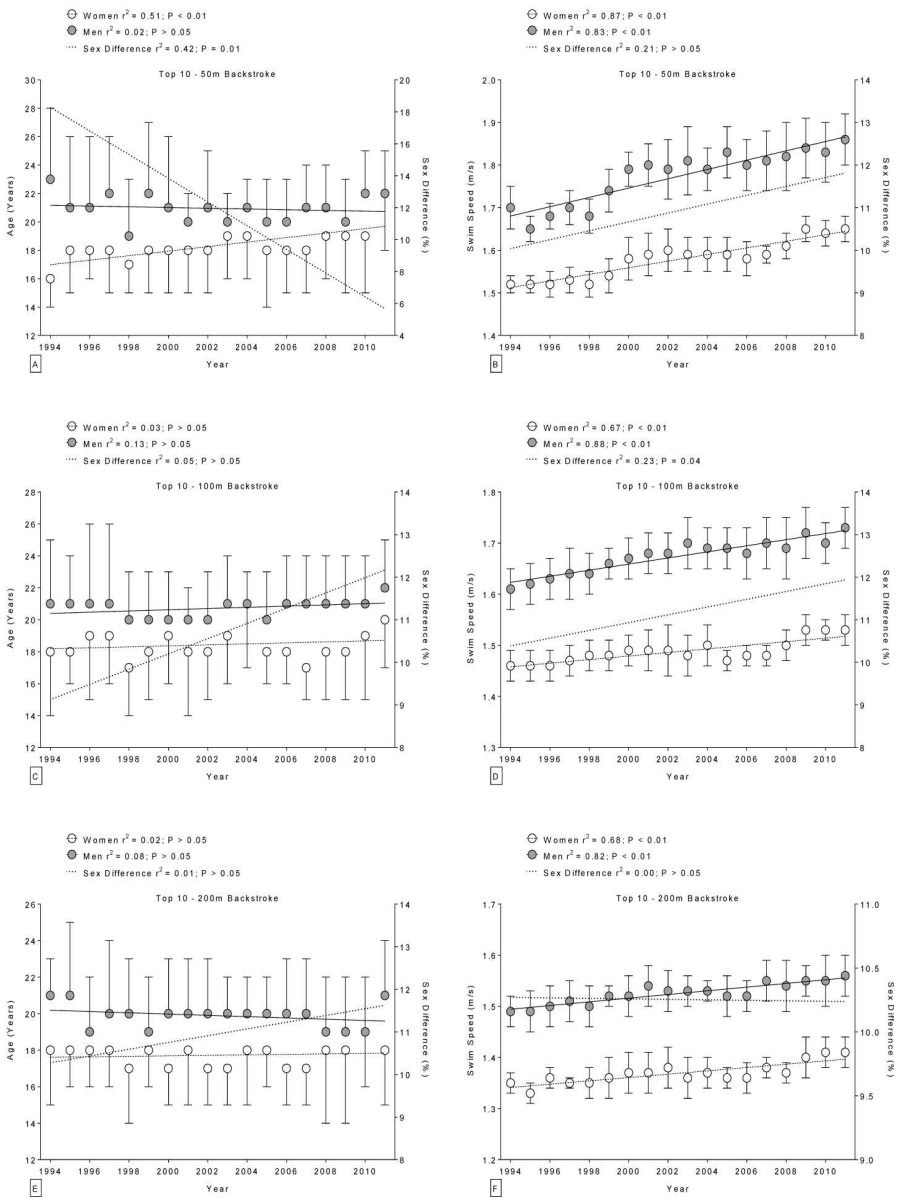

Figure 1: Change in age (panels A, C, E) and swimming speed (panels B, D, F) of the national backstroke swimmers for 50 m (panels A and B), 100 m (panels C and D) and 200 m (panels E and F) with sex difference across the years.

swim disciplines from 22.9% in 1916 to 8.9% in 1979 was documented[11]. Buhl et al.[12] analysed the change in swimming speed and sex differences in swimming speed for the 200-m and 400-m freestyle and medley from 1994 to 2011. Athletes of both sexes showed significant improvements in all disciplines across years with an increase of sex difference except for the 200-m medley. Except for Buhl et al.[12], recent data about sex difference in swimming performance are lacking, and it would be interesting to investigate the development of sex differences in swimming performance in the last 30 years. Furthermore, Schulz and Curnow[6] investigated the age of peak swimming performance for freestyle, but data about different strokes such as backstroke were not considered.

Therefore, the aim of this study was to examine the changes in swimming speed and age of peak swimming speed for both elite male and female swimmers at national and international levels in backstroke and freestyle from 1994 to 2011. There is only a small amount of literature about backstroke swimming in contrast to freestyle swimming; moreover, literature about freestyle swimming includes a great variety of different freestyle swim events. Therefore, there are limitations in the comparability of literature of swimming events. Hence, we decided to compare backstroke with freestyle as internal standard. We hypothesised that (i) the age of peak swimming speed of both elite Swiss swimmers and finalists at World Championships would decrease and swimming speed would increase over time for both women and men and (ii) the age of peak swimming speed would be lower for women compared to men for both backstroke and freestyle. To test this hypothesis, we analysed swimming speed of the top swimmers at national level (i.e. annual Swiss high score list)[13] and international level (i.e. finalists at World Championships which occurs every 4 years)[14,15] and compared the age the top 10 swimmers across years in backstroke and freestyle swimming for 50-m, 100-m and 200-m, respectively.

Materials and methods

All procedures used in the study met the ethical standards of the Swiss Academy of Medical Sciences[16] and were approved by the Institutional Review Board of Kanton St. Gallen, Switzerland, with a waiver of the requirement for informed consent of the participants, given the fact that the study involved the analysis of publicly available data.

Data sampling and data analysis

The data set from this study was obtained for national swimmers from

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Table 1 Age of peak backstroke swimming speed of national top 10 swimmers from 1994 to 2011 for men and women

	Age 1994	Age 2011	Significance	Sex difference 1994	Sex difference 2011	Significance
50-m backstroke						
Women	16 ± 2	22 ± 4	$P < 0.01$	28.19	2.31	$P = 0.01$
Men	23 ± 5	22 ± 3	$P > 0.05$			
100-m backstroke						
Women	18 ± 4	20 ± 3	$P > 0.05$	12.56	11.11	$P > 0.05$
Men	21 ± 4	22 ± 3	$P > 0.05$			
200-m backstroke						
Women	18 ±3	18 ± 3	$P > 0.05$	11.59	14.92	$P > 0.05$
Men	21 ± 2	21 ± 3	$P > 0.05$			

Age is presented in years as mean (±SD); sex difference is presented in % as mean (±SD).

the website of the Swiss Swimming Federation[13] and for international swimmers from the International FINA-Ranking[14,15]. All swimmers from the Swiss swimming high score list between 1994 and 2011 and the finalists of the World Championships of the International FINA-Ranking on the 50-m long course were analysed regarding swimming speed, sex and age.

Data were available from 1994 to 2011 for 207,852 athletes at national level and 369 athletes at international level. From the athletes competing at national level, the annual fastest race time and the race times of the annual top 10 athletes for the distances of 50-m, 100-m and 200-m in backstroke and freestyle were determined for both women and men. For the swimmers competing at international level, the eight finalists were included. When there were less than 10 male or female participants for a specific discipline in a year at national level, only the best annual performance was analysed.

Table 2 Age of peak backstroke swimming speed of international FINA World Championship swimmers from 1994 to 2011 for men and women

	Age1994	Age2011	Significance	Sex difference 1994	Sex difference 2011	Significance
50-m backstroke						
Women*	22 ± 4	23 ± 4	$P > 0.05$	16.44	13.50	$P > 0.05$
Men*	23±2	26 ± 1	$P > 0.05$			
100-m backstroke						
Women	21 ± 2	22 ± 4	$P > 0.05$	13.50	18.63	$P > 0.05$
Men	24 ± 1	24 ± 3	$P > 0.05$			
200-m backstroke						
Women	21 ± 3	19 ± 2	$P > 0.05$	15.01	15.37	$P > 0.05$
Men	23 ± 2	23 ± 4	$P > 0.05$			

Age is presented in years as mean (±SD); sex difference is presented in % as mean (±SD). *Data available from 2001.

In order to compare the swimming performance between the disciplines and distances, race times were transformed to swimming speed (m/s) using the equation [race distance in metres]/[race time in seconds]. To compare male and female performances, the sex difference was calculated using the equation ([swimming speed in women] – [swimming speed in men])/[swimming speed in men] × 100, where sex difference was calculated for every pairing of equally placed athletes (e.g. between male and female first place, between male and female second place, etc.) before calculating the mean value and standard deviation (SD) of all the pairings. In order to facilitate reading, all gender differences were transformed to absolute values before analysing. No athlete was included twice or several times in the same year because Swiss Swimming Federation lists only the best performance per year of an athlete in the same year.

Statistical analysis

In order to increase the reliability of data analyses, each set of data was tested for normal distribution as well as for homogeneity of variances in advance of statistical analyses. Normal distribution was tested using a D'Agostino and Pearson omnibus normality test and homogeneity of variances was tested using a Levene's test. To find significant changes in a variable across years, single linear regression analysis was used. Two-way analysis of variance (ANOVA) with Bonferroni post-hoc analysis was used to analyse differences between the annual top 10 women and men. Statistical analyses were performed using IBM SPSS Statistics (Version 19 and 21, IBM SPSS, IL, USA) and GraphPad Prism (Version 5 and 6, GraphPad Software, CA, USA). Significance was accepted at $P < 0.05$ (two sided for *t*-tests). Data in the text are given as mean ± SD.

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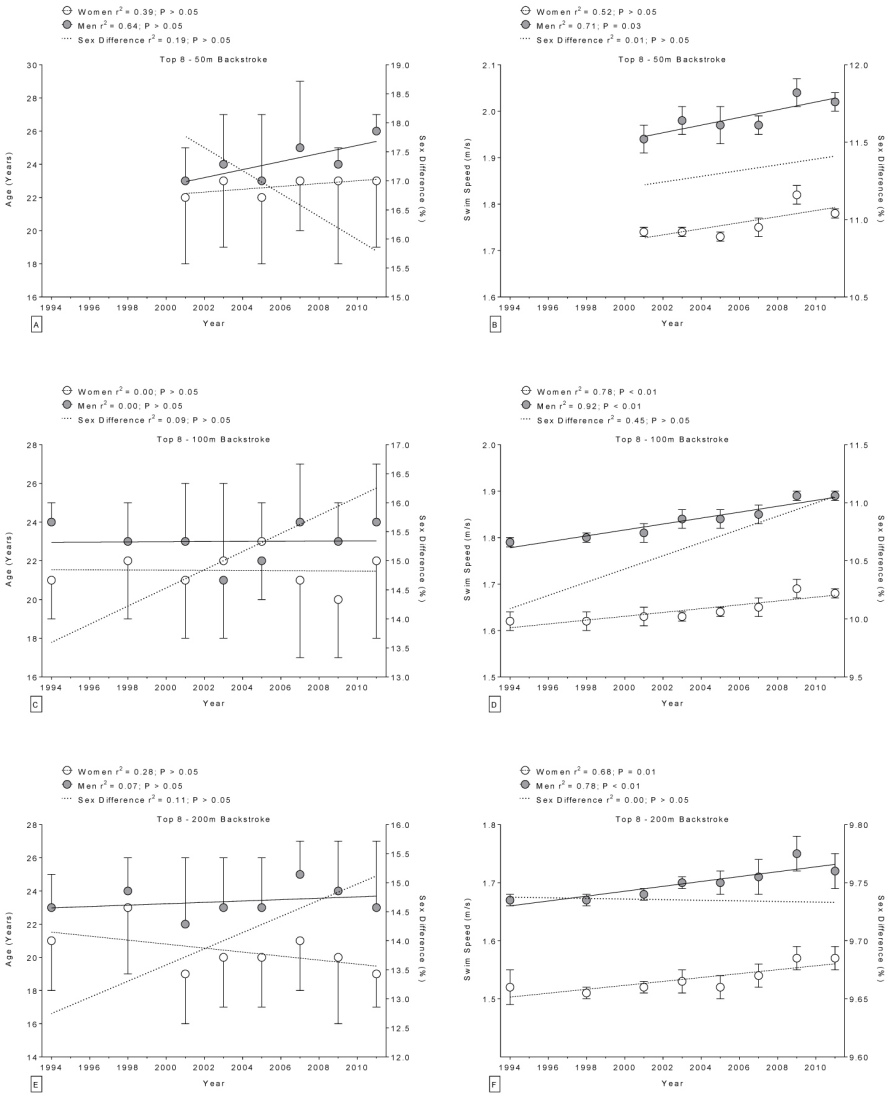

Figure 2: Change in age (panels A, C, E) and swimming speed (panels B, D, F) of the international backstroke swimmers for 50 m (panels A and B), 100 m (panels C and D) and 200 m in backstroke (panels E and F) with sex difference across the years.

Results

Change in the age of peak swimming speed across years

In backstroke, women at national level achieved the age of peak swimming speed at a younger age (16–22 years) (Table 1, Figure 1A, 1C, 1E) compared to women at international level (19–23 years) (Table 2, Figure 2A, 2C, 2E). Only in 50-m backstroke in athletes competing at national level, a change in the age of peak swimming speed was observed from 16 to 22 years (Table 1, Figure 1A).

The age of peak swimming speed in backstroke was older for men than for women. Furthermore, the age of peak swimming speed was older for swimmers at international level (23–26 years) (Table 2, Figure 2A, 2C, 2E) than in swimmers at national level (21–23 years) (Table 1, Figure 1A, 1C, 1E). However, in backstroke, no changes in the age of peak swimming speed were observed across years. The sex difference in swimming speed remained stable across the years, with the exception of 50-m backstroke of national swimmers with a decline from 28.2% to 2.3% across years (Table 1, Figure 1A).

In freestyle, no changes in the age of the fastest swimming speed were observed for both sexes in all distances neither on national (Table 3, Figure 3A, 3C, 3E) nor on international (Table 4, Figure 4A, 4C, 4E) level. Only in the 50-m freestyle of men competing at national level (Table 3, Figure 3A), a significant decline from 23 to 22 years was observed. However, again the age of the highest swimming speed was lower for swimmers competing at national level (women 18–21 years; men 21–23 years) compared to athletes competing at international level (women 19–25; men 22–25 years). While the sex differences in swimming speed declined significantly in all distances in athletes at national level (mean from 16.3% to 8.8%) (Table 3, Figure 3A, 3C, 3E), the sex difference in swimming speed of athletes competing at international level remained unchanged across years (mean 17.1% to 14.3%; $P > 0.05$) (Table 4, Figure 4A, 4C, 4E).

Change in swimming speed across years

The swimming speed increased across years, with the exception of the 50-m backstroke for women competing at international level (Table 5). Women showed a smaller improvement in swimming speed than men, with a greater improvement in backstroke than in freestyle. However, swimmers competing at national level (Tables 6 and 7) showed greater changes in swimming speed compared to swimmers competing at international level (Tables 5 and 8). The change in swimming speed depending on distance for women showed an improvement with a range from 4.4% to 8.5% in backstroke and from 2.4% to 2.8% in freestyle in swimmers

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Table 3 Age of peak freestyle swimming speed of national top 10 swimmers from 1994 to 2011 for men and women

	Age 1994	Age 2011	Significance	Sex difference 1994	Sex difference 2011	Significance
50-m freestyle						
Women	19 ± 2	20 ± 3	P > 0.05	18.53	12	P < 0.01
Men	23 ± 4	22 ± 3	P < 0.01			
100-m freestyle						
Women	18 ± 2	21 ± 4	P > 0.05	18.92	9.09	P = 0.04
Men	22 ± 4	23 ± 3	P > 0.05			
200-m freestyle						
Women	19 ± 3	20 ± 2	P > 0.05	11.48	5.39	P < 0.01
Men	21 ± 2	22 ± 4	P > 0.05			

Age is presented in years as mean (±SD); sex difference is presented in % as mean (±SD).

competing at national level. Women competing at international level showed a range from 3.3% to 3.7% in backstroke and from 1.8% to 3.0% in freestyle. Men competing at national level, however, showed a range of improvement in swimming speed from 4.7% to 9.4% in backstroke and from 4.4% to 5.3% in freestyle, while male athletes competing at international level showed a range from 3.0% to 5.6% in backstroke and from 2.7% to 3.5% in freestyle. However, due to a greater improvement in swimming speed in men compared to women, the sex difference in swimming speed increased in the 100-m backstroke (Table 6, Figure 1D) and all freestyle distances of swimmers at national level (Table 7, Figures 2 B, 2D, 2F). In swimmers at international level, the sex differences in swimming speed remained unchanged across years (Tables 5 and 8, Figure 3B, 3D and Figures 4B, 4D, 4F).

Discussion

The aim of this study was to examine the changes in swimming speed and the age of peak swimming speed for both elite male and female swimmers at national and international levels in backstroke versus freestyle from 1994 to 2011. According to our hypothesis, women achieved peak swimming speed at a younger age than men in both disciplines and all distances. During the studied period, peak swimming speed improved at a greater extent for men than for women in all distances and both strokes on both national and international levels.

Women achieved the age of peak swimming speed at a younger age than men

A first important finding was that women achieved peak swimming speed in freestyle and backstroke at a younger age than men. In all distances, women reached peak swimming speed at ~18 years in backstroke and at ~19 years in freestyle. For men, peak swimming speed in 50 m was achieved at ~20 years in backstroke and at ~22 years in freestyle and at 21 years in 100 m for both disciplines.

These findings are in line with Schulz and Curnow[6] investigating the age of peak performances in different sport events including different freestyle swimming events. However, in the present study, athletes of both sexes achieved peak swimming speed in freestyle and backstroke at higher ages compared to previous data. Schulz and Curnow[6] found the age of peak swimming speed in freestyle for women at ~17 years and for men at ~19 years, respectively. A potential explanation for these different findings might be the analysed period of time. Schulz and Curnow[6] analysed data from 1896 to 1980, while our results are based on a data from 1994 to 2011. Schulz and Curnow[6] separated their data into a period before and after World War II. Men showed a decline in the age of peak swimming performance after World War II while women showed an increase after World War II. These

Table 4 Age of peak freestyle swimming speed of international FINA World Championship swimmers from 1994 to 2011 for men and women

	Age 1994	Age 2011	Significance	Sex difference 1994	Sex difference 2011	Significance
50-m freestyle						
Women	20 ± 4	25 ± 5	P > 0.05	16.03	14.44	P > 0.05
Men	23 ± 2	25 ± 3	P > 0.05			
100-m freestyle						
Women	20 ± 4	24 ± 3	P > 0.05	15.48%	13.08	P > 0.05
Men	23 ± 3	24 ± 3	P > 0.05			
200-m freestyle						
Women	19 ± 3	21 ± 2	P > 0.05	19.79%	15.42	P > 0.05
Men	22 ± 3	24 ± 3	P > 0.05			

Age is presented in years as mean (±SD); sex difference is presented in % as mean (±SD).

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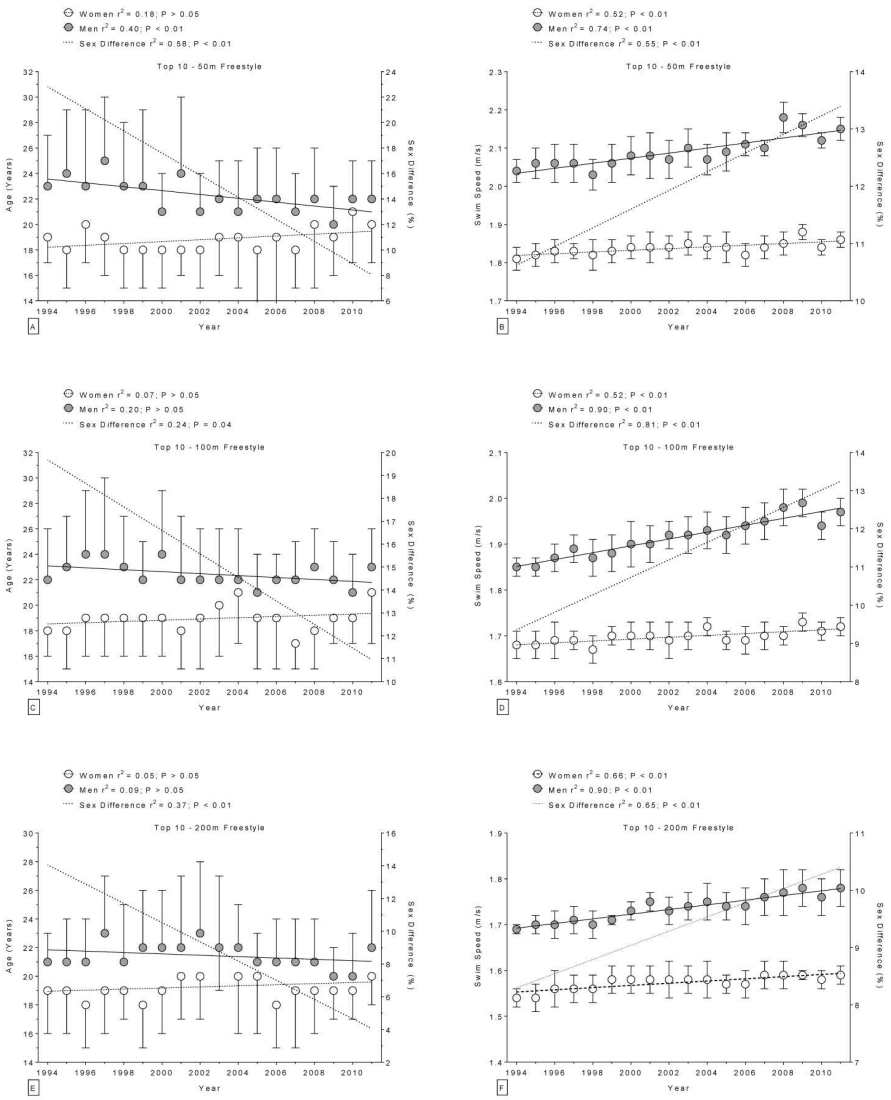

Figure 3: Change in age (panels A, C, E) and swimming speed (panels B, D, F) of the national freestyle swimmers for 50 m (panels A and B), 100 m (panels C and D) and 200 m (panels E and F) with sex difference across the years.

changes across the last century can be explained by geopolitical differences and historical developments[17] on the one hand and by developments in training techniques and improvement in swimming techniques related to a greater knowledge of biological and physiological processes[18] on the other hand.

Swimming performances are related to specific body profile markers[19]. Therefore, changes in the age of fastest swimming speed can be related to changes in anthropometric pattern across time. A variety of studies showed an increment on both body height and body weight among children over the last century in different countries such as Japan[20,21], Turkey[22], Brazil[23], Poland[24] and China[25,26]. This phenomenon seemed to be related to environmental and socioeconomic factors such as changes in optimised nutrition and improvement in health and hygienic systems[20,26].

Furthermore, specific body profile markers of swimmers such as body height, length of extremities and body weight were attributed to predict swimming performances in different swim events already at preadolescent age[19]. While sprint and backstroke swimmers were taller, heavier and showed longer extremities, short and light swimmers showed a better performance in long-distance and butterfly events[19]. Charles and Bejan[27] analysed male champions in 100-m freestyle swimming and 100-m dash running from 1912 to 2008. They described that during the last century, male champion swimmers became taller and heavier and achieved higher swimming speeds by producing more power due to optimal locomotion conditions[27].

Due to differences in body compositions of men and women, swimming performances of the sexes are related to different anthropometric markers. Geladas et al.[28] analysed predictor variables in freestyle swimming performance for men and women. For male swimmers, upper-extremity length, horizontal jump and grip strength were significant predictors for performances in freestyle swimming, whereas body height, upper extremity and hand length, shoulder flexibility and horizontal jump were value predictors for female swimmers[28]. Based on these facts, sex differences in swimming performance seemed to be influenced by the earlier onset of maturation in women compared to men[29,30]. These differences in development effects on the one hand bone growth and on the other hand the development and distribution of body fat.

Regarding bone growth, girls reach the maximum of all bone variables at younger age than boys[31]. Martin et al.[29] described a difference of approximately 2 years between the growth of metacarpal bones between girls and boys. Compared to an adult bone mineral content and volumetric den-

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Table 5 Changes in swimming speed in backstroke across from 1994 to 2011 for international FINA World Championship swimmers

	Changes (m/s)	Changes (%)	Signif-icance	Sex differ-ence 1994	Sex differ-ence 2011	Signifi-cance
50-m backstroke						
Women	+0.04	+2.3	P > 0.05	10.28	11.50	P > 0.05
Men	+0.08	+4	P = 0.03			
100-m backstroke						
Women	+0.06	+3.7	P < 0.01	9.58	10.07	P > 0.05
Men	+0.10	+5.6	P<0.01			
200-m backstroke						
Women	+0.05	+3.3	P = 0.01	9.46	9.14	P > 0.05
Men	+0.05	+3	P < 0.01			

Changes in swimming speed are presented in m/s and %.

sity, boys reach approximately 86% while girls show 93% at an age of 17 years[31]. However, the performance of swimmers between 14 and 16 years in 100-m freestyle was partly predictable by anthropometry and physical capacity with lower value for boys and girls[28].

Besides different changes of the skeleton during puberty, boys and girls show a different development in body fat and muscle mass. The change in both the proportion and the distribution of body fat seemed to influence swimming performance[32–34]. During puberty, girls develop more fat mass compared to boys, while both gain more muscle mass[35]. At the age of ~11 years, boy sprint swimmers presented 9.4% fat and girl sprint swimmers 12.7% fat[34]. In the last stages of and after puberty, women obtain more fat mass[30]. Adult female swimmers have a per cent body fat of 14–19% than male swimmers of 5–10%[36]. The locations of body fat and body mass affect the centres of buoyancy, and this influences kick performance and swimming performances respectively[37]. Especially, women have proportionally more fatty tissue located caudally compared to men, and therefore centre of buoyancy is different for the sexes. Special training programs may help to reduce the proportion of body fat especially for women to improve their swim performances[34].

Sex difference in swimming performance

Men achieved a higher swimming speed in all distances and disciplines than women, with higher swimming speeds in freestyle compared to backstroke. Furthermore, swimming speed declined with increasing distance for all distances and disciplines on national and international levels. For both sexes and all disciplines and distances, the swimming speeds of the international athletes were higher than of the national swimmers. This finding is in line with existing literature[12,38].

Swimming speed depends on a variety of different patterns. Besides anthropometric factors as mentioned, different physiological parameters and swimming techniques have an impact on swim speed[39]. Physiological pattern such as metabolic responses and the ability of the body to adapt have an effect on swimming speed. The energy cost of a performance is related to the oxygen consumption, cardiopulmonary response and metabolic adaptations[40]. Analysing the energy cost of different swimming styles, freestyle has a lower value than backstroke[41]. Men have a higher VO_2max compared to women, but this difference disappears when normalising to leg mass[40]. Fomin et al.[40] analysed the sex difference of physiological markers at maximal exercise stress. Women showed significantly lower levels in the cardiopulmonary markers such as maximal systolic blood pressure, ventilation and ventilated lung volume. The maximal heart rate was similar between both sexes, but

Table 6 Changes in swimming speed in backstroke across from 1994 to 2011 for Swiss top 10 swimmers

	Changes (m/s)	Changes (%)	Signifi-cance	Sex differ-ence 1994	Sex differ-ence 2011	Signifi-cance
50-m backstroke						
Women	+0.13	+8.5	P < 0.01	10.58	10.92	P > 0.05
Men	+0.16	+9.4	P < 0.01			
100-m backstroke						
Women	+0.07	+4.8	P < 0.01	9.36	10.01	P = 0.04
Men	+0.12	+7.5	P < 0.01			
200-m backstroke						
Women	+0.06	+4.4	P < 0.01	9.59	10.01	P > 0.05
Men	+0.07	+4.7	P < 0.01			

Changes in swimming speed are presented in m/s and %

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Research study

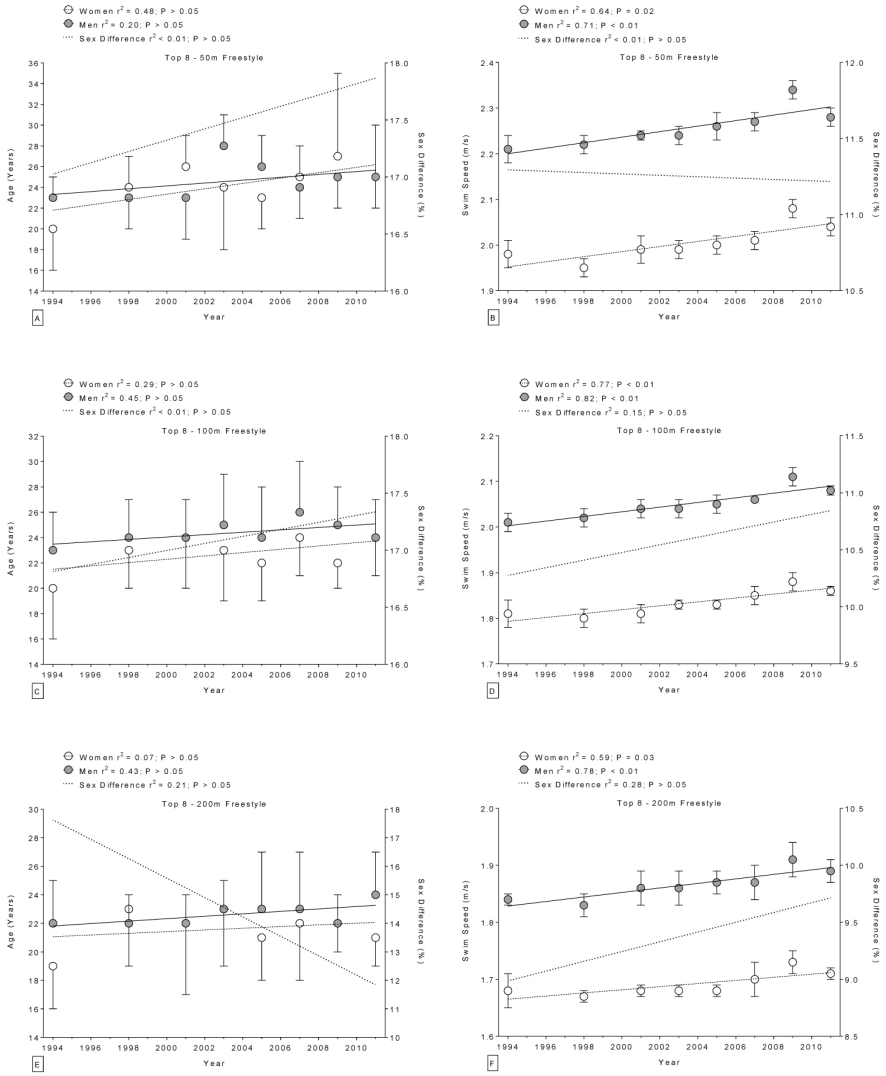

Figure 4: Change in age (panels A, C, E) and swimming speed (panels B, D, F) of the international freestyle swimmers for 50 m (panels A and B), 100 m (panels C and D) and 200 m in freestyle (panels E and F) with sex difference across the years.

women performance is limited due to a longer rate-corrected QT interval (time of ventricular de- and repolarisation). The metabolic factors such as blood pH, base excess and blood bicarbonate were similar between men and women with minimal lower levels of blood lactate for men[40].

These physiological factors seemed to be related to the different levels of muscle power of the sexes. Men have a higher peak leg power compared to women[42–46] mainly due to their higher lean leg volume[42,44,46]. Seifert et al.[47] analysed kinematic changes during a 100-m front crawl sprint for both sexes. High-speed swimmers were characterised by a higher and more stable stroke length. Men swim faster than women because of the greater body height and arm span[48].

The differences in swimming speed between international and national swimmers can firstly be related to the greater amount of competitors with tighter concentration of the top athletes with top performances. Secondly, international swimmers produce stability in performances with energetic and biomechanical capacities continuously[49]. Another finding was that the sex difference of national swimmers became greater across the years for 100-m backstroke and all freestyle distances with no changes in international level.

Analysing the change of the sex differences in all swimming events across time, Thiebault et al.[11] found a balance in the sex difference in different world records since 1983. With increasing distance, the sex difference became smaller but the levels of sex difference for all swim distances and disciplines are lower than at our data; however, this can be influenced by the greater period of the collected data. Nevill et al.[38] analysed the100-m, 200-m and 400-m freestyle swimming world records from 1957 to 2006 and showed that the sex difference in freestyle remained stable between 8% and 11%. For the 100-m freestyle, the sex difference was at 11%, for the 200-m freestyle it was at 10% and for the 400-m freestyle it was at 9%[38]. Due to these reasons, a further decline in sex difference might be observed in the future; however, women will not be able to reach the same level as men.

Improvement of swimming speed across years

Our data showed that athletes of both sexes enhanced swimming speed in all distances and disciplines at both national and international levels over the analysed period. The improvement of swim speed throughout years is in agreement with the findings of Berthelot et al.[50] and Nevill et al.[38]. Berthelot et al.[50] analysed data of swimming events from 1963 to 2008, and despite other sports, e.g. track and field, performances in swimming still improved. Nevill et al.[38] analysed world records in 100-m, 200-m and 400-m front crawl swimming from 1957 to 2006. They argued that the improvements between the 1950s and 1960s for men

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Table 7 Changes in swimming speed in freestyle across from 1994 to 2011 for Swiss top 10 swimmers						
	Changes (m/s)	Changes (%)	Significance	Sex difference 1994	Sex difference 2011	Significance
50-m freestyle						
Women	+0.05	+2.8	P < 0.01	10.86	13.30	P < 0.01
Men	+0.11	+4.4	P < 0.01			
100-m freestyle						
Women	+0.04	+2.4	P < 0.01	9.65	12.74	P < 0.01
Men	+0.12	+6.5	P < 0.01			
200-m freestyle						
Women	+0.04	+2.6	P < 0.01	8.77	10.68	P < 0.01
Men	+0.09	+5.3	P < 0.01			
Changes in swimming speed are presented in m/s and %.						

and between 1960s and 1970s for women were due to better coaching techniques based on better physiological, biomechanical and psychological knowledge. The impact of the social historical bias in sex difference was great in the early twentieth century. However, biological factors are more important to understand the sex difference today[51].

Berthelot et al.[50] suggested that age of peak performance might be confounded by introducing a new generation of swimsuits with better hydrodynamic characters. O`Connor et al.[52] analysed swimming performances of FINA World Championship in different strokes and distances from 1990 to 2011, with the aim to confirm the influence of technical improvement. Due to the fact that the performances are limited, there were 43 new world records registered at the 2009 World Championship in Rome. At the same time, the full-body polyurethane swimsuit was introduced. O`Conner et al.[52] claimed the new swimsuit as the main reason for these world records based on the fact that most world records still stand after excluding the full-body swimsuit in 2010. The present data showed significant improvements in swimming speed across the analysed period. Due to the small period, a plateau was not observed.

Limitations

This cross-sectional data analysis analyses and compares data of national and international swimmers during a period of 17 years. However, it is limited due to lack of determination of body composition[30,34,35,53]. It is known that they interact with swimming performance[54]. Further studies should include data about body height and weight, body fat and other

Table 8 Changes in swimming speed in freestyle across from 1994 to 2011 for international FINA World Championship swimmers						
	Changes (m/s)	Changes (%)	Significance	Sex difference 1994	Sex difference 2011	Significance
50-m freestyle						
Women	+0.06	+3.0	*P* = 0.02	10.64	10.74	P > 0.05
Men	+0.07	+3.1	*P* < 0.01			
100-m freestyle						
Women	+0.05	+2.8	*P* < 0.01	9.67	10.64	P > 0.05
Men	+0.07	+3.5	*P* < 0.01			
200-m freestyle						
Women	+0.03	+1.8	*P* = 0.03	8.77	9.48	P > 0.05
Men	+0.05	+2.7	*P* < 0.01			
Changes in swimming speed are presented in m/s and %.						

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anthropometric pattern. Information about nutrition and fluid intake was not recorded, which are known to influence individual performances[55]. Dependent on age and sex, individual demands on nutrition were described[55,56]. Furthermore, data about training strategies to improve swimming techniques[47,48,57–61] to optimise recovery phases[18,62] and warming-up phases[63,64] which have an effect on swimming performances were not registered. Information about motivation and goal orientation was not recorded. General gender-related differences in motivation[65], the influence of perfectionism[66] and mental preparation strategies[67] are supposed to influence performance.

Conclusion

The present results showed that for freestyle and backstroke and for swimming distance ranging from 50 m to 200 m, elite female swimmers competing at national and international levels achieved peak swimming speed at a younger age (~18–23 years) compared to men (~21–26 years). Across the analysed period, the sex differences in the age of peak swimming speed in backstroke decreased for 50 m and for all distances in freestyle swimming for swimmers competing at national level, while no changes were found for athletes competing at international level. The swimming speed improved over the years in a greater extent for men than for women in all distances and disciplines. Future studies should include data about other swimming styles and the development in a greater variety of distances over a greater analysed period of time.

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